

EXPLOSIVE SAFETY SITING OF CORPS OF ENGINEERS

STANDARD IGLOO DESIGNS

by

Earl Williams  
Adib Farsoun  
Wallace Watanabe

U. S. Army Engineer Division, Huntsville  
Huntsville, Alabama

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ABSTRACT

The U.S. Army Corps of Engineers maintains a family of "Standard Design" storage magazines. These designs are used throughout the Department of Defense (DOD) to store explosives and munitions. The DOD 6055.9-STD defines the approved safety siting and quantity limits for "standard" and "nonstandard" magazines. Several of the Corps "Standard Designs" are directly referenced by the DOD 6055.9-STD. There is a serious lack of understanding of the limitation on the use of Corps "Standard Design" magazines as "Standard" or "Nonstandard" storage as defined by DOD 6055.9-STD. This paper provides guidance in understanding the proper use of the Corps Standard Igloo Designs to comply with the explosive safety requirements of the DOD standard.

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## BACKGROUND

General. The Corps of Engineers magazine standard designs have been developed in coordination with the Department of Defense Explosive Safety Board (DDESB) so that the designs would be considered preapproved when called for in construction. The DDESB's approved Army earth-covered magazines include 33-15-65, 33-15-74, 421-80-01, and 422-15-01. These standard designs are, for the most part, a complete set of construction drawings. The magazines must, however, be tailored (site-adapted) for local conditions which mainly involve the foundation. The later magazine 422-15-01 has been developed for storage and segregation of small quantities of ammo or explosives.

Siting. The above magazines, when sited to requirements of DOD 6055.9-STD, (Reference 1), will prevent communication of explosion from one magazine to another. Siting requirements as described in DDESB criteria documents are greatly influenced by the classification of the magazine, that is, whether the magazine is "Standard" or "Nonstandard". Siting requirements for those magazines labeled "Standard" are:

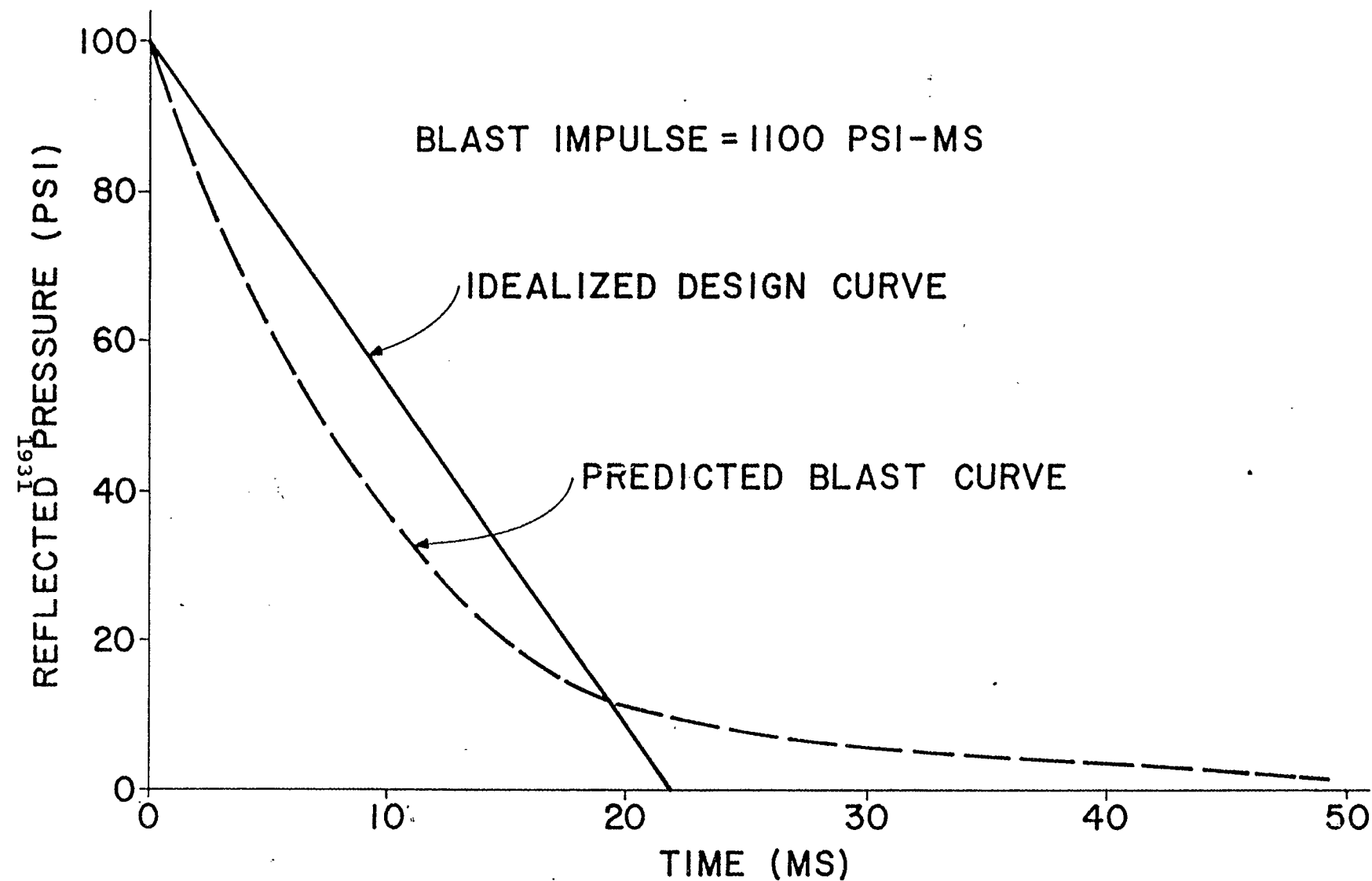
<u>Orientation</u>	<u>Intermagazine Separation</u>
Side-to-Side	$1.25 W^{1/3}$
Rear-to-Front	$2.00 W^{1/3}$
Side-to-Front	$2.75 W^{1/3}$

### Design Requirements for Standard Magazines

- Minimum earth cover shall be 2 feet.
- Slope of earth fill shall be 2 horizontal to 1 vertical
- Headwall including door shall be designed for 1100 psi-ms shown in Figure 1.
- Stones larger than 10 pounds shall not be used as part of back-fill to cover arch above spring lines.

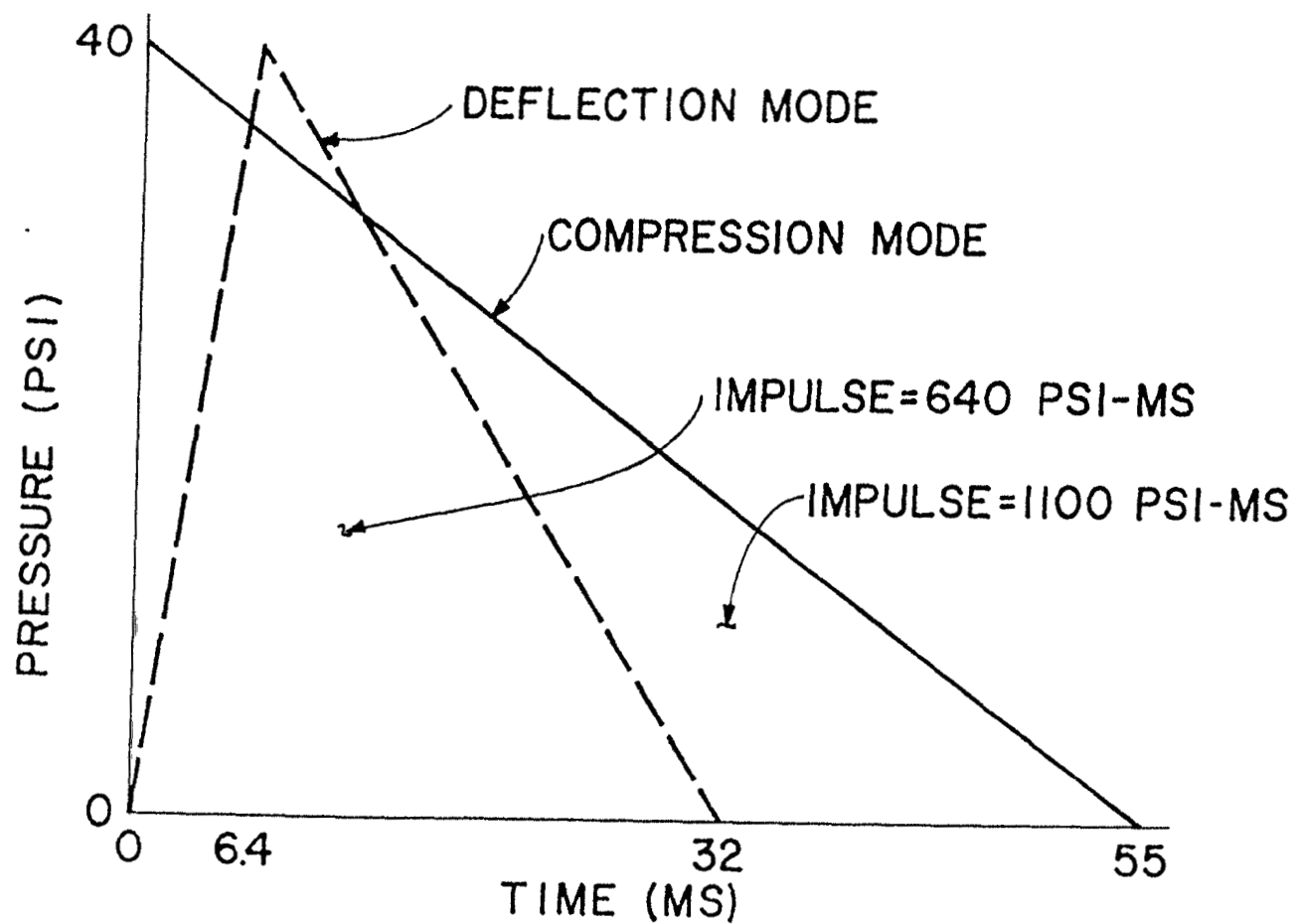
## DEFINITIONS

- Standard Earth-Covered Magazine. A magazine of the designation listed above and listed in DOD 6055.9-STD. It is a magazine approved for the storage of 500,000 pounds net explosive weight (NEW).



IDEALIZATION OF PRESSURE-TIME FUNCTIONS (REF. 8)

FIGURE 1



COMPRESSION AND DEFLECTION MODE LOADINGS (REF. 8)

FIGURE 2

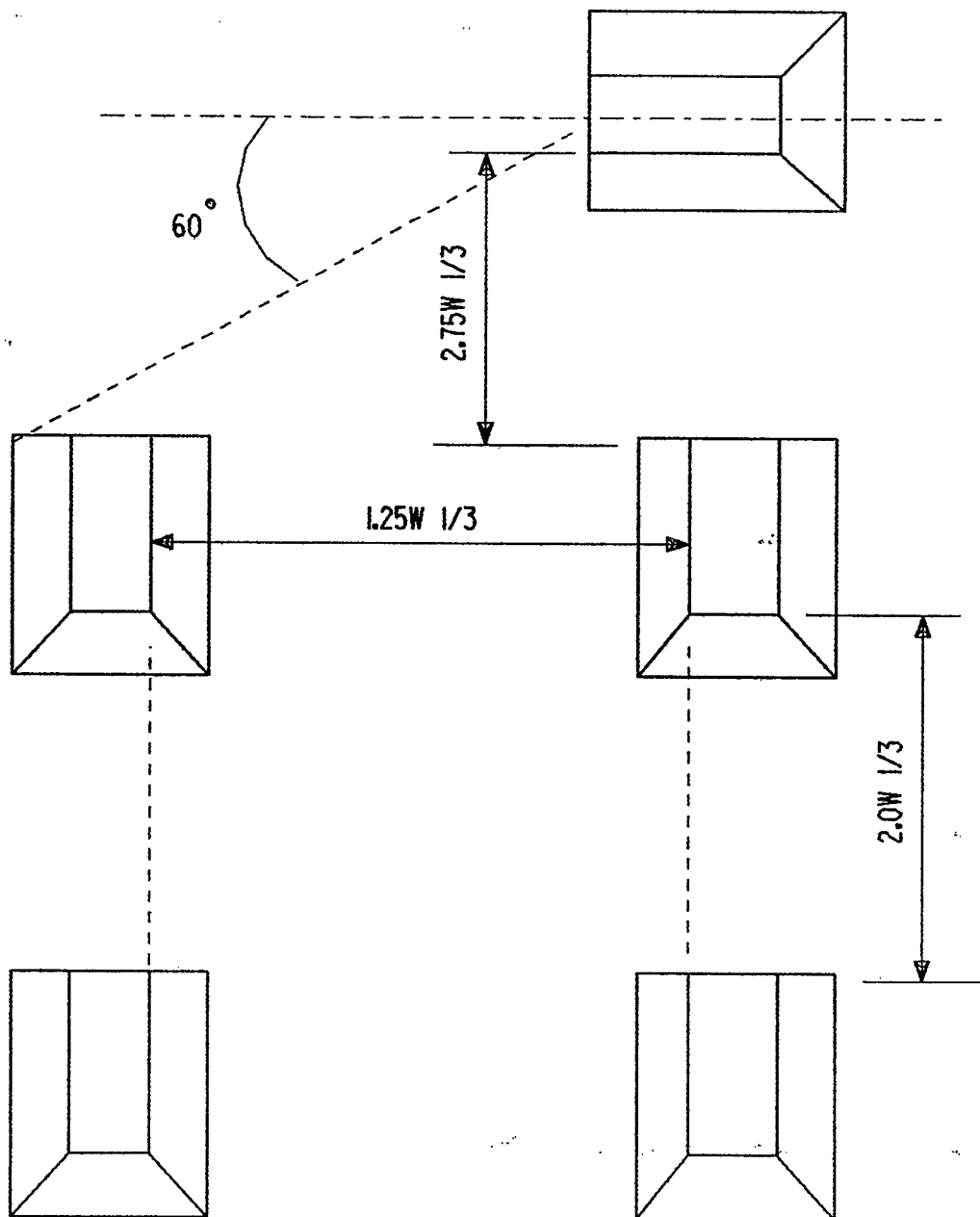


FIGURE 4 (REF.9)

b. Nonstandard Earth-Covered Magazine. A magazine that is not equivalent in strength to the standard magazine (weaker structurally) and is limited in storage to 250,000 pounds of NEW.

c. Hybrid Earth-Covered Magazine. A magazine that uses components from standard magazines, and/or modifications therefrom. These magazines cannot be considered preapproved, therefore, they require submission to the DDESB for approval prior to construction.

## REQUIREMENTS TO QUALIFY AS STANDARD IGLOO MAGAZINE

### Critical Structural Elements

The performance of an earth covered igloo storage magazine is dependent on four primary structural elements:

- Earth Covered Arch
- Rear wall (Bermed)
- Headwall
- blast Doors

Each of these elements must be demonstrated by test (or in some cases by analysis) to be capable of preventing simultaneous propagation by resisting the blast forces that can occur for the maximum storage quantity at the minimum standard siting distance. (See Figures 1 and 2 for loading.) A standard magazine is intended to provide a desired degree of asset protection. Criteria in DOD 6055.9-STD is intended to be consistent with this requirement.

### Test Verification Programs

After World War II, there remained on hand in the United States and overseas a tremendous stockpile of munitions. Available space at depots was limited based on the quantity distance limits being applied at that time. To provide for an orderly and economical disposition of these huge stocks of ammunitions, it was necessary to determine whether existing igloo storage capacities could be safely expanded without requiring large expenditures for additional land, roads and properties. A full scale test program was conducted by the Army-Navy Safety Board (a predecessor to the DDESB) at the Naval Proving Ground at Arco, Idaho (Reference 2). The purpose of this test was to determine the ability of the existing igloo structures to safely accommodate larger storage limits at the same or closer inter-magazine distances. The results of this test program showed that the storage limits for the igloo configuration tested could be safely increased to 500,000 lbs. at a separation distance of  $5W^{1/3}$ . In fact, the test indicated that siting at separations of  $2.5W^{1/3}$  was feasible. Igloos

in this test were the two Army and two Navy standard concrete, arch type, earth-covered igloo magazines, approximate size of 26'-6" wide by 81'-0" long.

In the 1970's the DDESB undertook an extensive test program to attempt again to reduce the required separation distance for igloo storage. This test program was called the Explosive Safety Knowledge Improvement Operation (ESKIMO). These tests were conducted at the Naval Weapons Center, China Lake, California. The results of these tests are documented in References 3 through 7. The Eskimo I test in 1971 demonstrated that the most critical element in the performance of an igloo magazine was the door. It was determined that increased storage potential could be obtained through an improved door design. ESKIMO I testing was based on igloo configurations similar to the 33-15-64. The ESKIMO II tests conducted in 1973 considered a stronger door design and highlighted the need for a balanced design for the strength of the headwall and door. Changes in the door and headwall for this test consisted of a large single leaf sliding door and a strengthened headwall.

The following is a summary of the ESKIMO tests:

ESKIMO I (Reference 3), the first test, was conducted in December 1971 to determine a safe, practicable minimum separation distance for face-on exposures of the U.S. Army steel arch magazines. Explosion communication occurred to an acceptor igloo of this design at a distance in feet equal to  $1.25W^{1/3}$ , in which W is the weight in pounds of the high explosive in storage, but failed to occur at a distance of  $2.0W^{1/3}$  to the rear of the donor. Further, the test revealed that safety and economy might be increased through improved design for closer balance in strength between the doors and headwall of the magazine.

ESKIMO II (Reference 4) was conducted in May 1973 to appraise magazine door and headwall designs. A large, single-leaf sliding door withstood the blast with minor distortion although the accompanying headwall sustained severe damage. A Stradley-type headwall, on the other hand, incurred only minor damage. In addition, the noncircular (oval) steel arch with concrete thrust beams was tested with the Stradley headwall and withstood the blast without breakup or severe distortion.

ESKIMO III (Reference 5) conducted in June 1974 further extended the study of explosives-storage magazines using information derived from ESKIMO I and II. During a further test of the oval arch and Stradley-type headwall, ESKIMO III used structures remaining from ESKIMO II, rebuilt as necessary, as well as new construction of a light-gauge, deeply corrugated, steel-arch magazine. The oval-arch magazine tested in ESKIMO II was fitted with a newly designed Stradley-type headwall with a single-leaf door. ESKIMO II proved that the Stradley-type headwall could withstand a face-on impulse of 1,750 psi-ms and that the steel oval-arch could



withstand the face-on impulses generated by that charge. ESKIMO III tested the ability of the new headwall to withstand the side-on blast imposed by the explosion of the adjacent magazine.

ESKIMO IV (Reference 6) conducted in September 1975 continued the study of explosive storage magazines, using information from the prior tests in the ESKIMO series. The door and headwall combination used on the oval-arch magazine was tested again in ESKIMO IV but with face-on blast loading as compared with the side-on loading experienced with ESKIMO III. The door that had fallen off its supports in ESKIMO III was rehung in position. ESKIMO IV provided the initial test of the combination of a newly designed headwall and single-leaf sliding door under face-on loading. ESKIMO IV also included a rebuilt standard headwall and door (OCE standard drawing 33-15-64) as a control structure and a single-leaf sliding door remaining from ESKIMO III in combination with a rebuilt standard headwall. The response of the magazines was essentially as expected with only minor damage occurring.

ESKIMO V (Reference 7) was a continuation of the study of explosive-storage magazines using information from the prior ESKIMO tests. The oval steel-arch igloo used in ESKIMO III (side on loading) and ESKIMO IV (headwall loading) was again tested. The earth cover and the concrete thrust beams were removed, and the fill was replaced. ESKIMO V also included a newly constructed magazine of the FRELOC concrete arch type. Since door response was not a concern in this test, nonpermanent steel doors were spot welded or bolted to the door openings of the igloos. The structural response of the magazines in this test was essentially as predicted and well within acceptable limits.

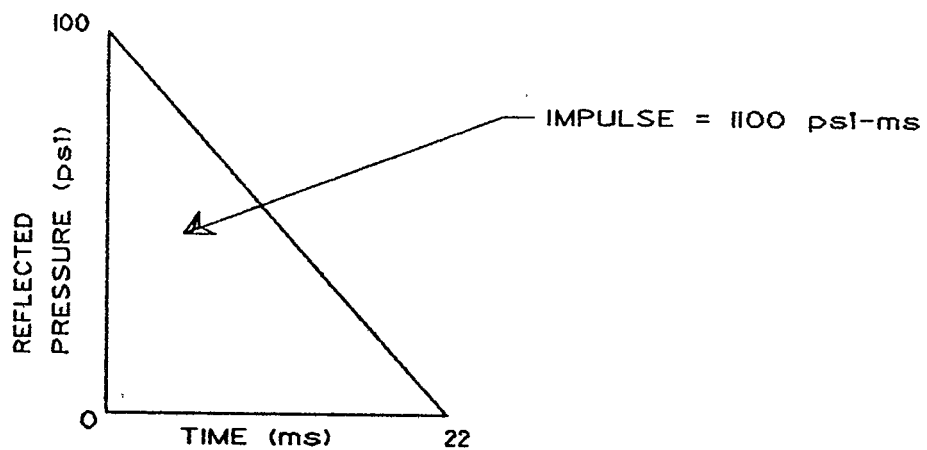
ESKIMO VI and VII tested the Navy box-type magazines which are not covered in this paper.

#### Limitation on Stones in Earth Cover

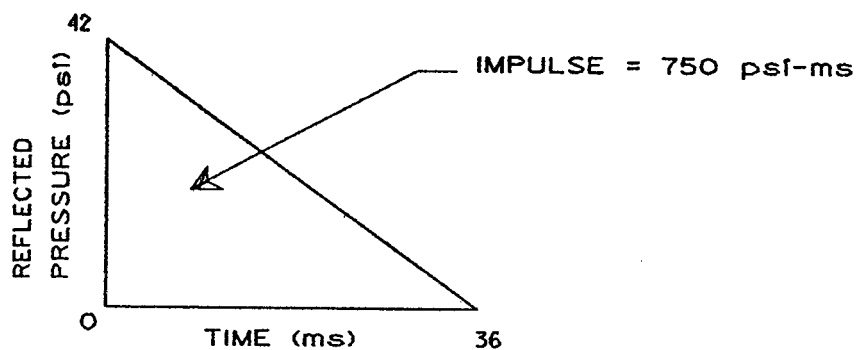
In the event of the accidental detonation of a storage magazine, the earth cover will be ejected at high velocities. The presence of large stones or debris would create an undesirable secondary fragmentation risk (Reference 1). To minimize this problem, the standard igloo magazines have clearly specified limits on material allowed over the crown of the arch.

#### **EFFECT OF MAGAZINE SEPARATION ON HEADWALL/DOOR LOADING.**

As the separation between igloos increase, the loading on the headwall/door decreases. For a comparison of loading for a side-to-side spacing of  $1.25W^{1/3}$  and  $5.0W^{1/3}$ , see Figure 3. For any igloo sited between these two spacing of igloos, a new loading can be developed.



a. FOR 1.25 W  $1/3$  , REFERENCE 8



b. FOR 5.0 W  $1/3$  , REFERENCE 9

FIGURE 3 BLAST LOADING FOR SIDE TO SIDE IGLOOS

## REVIEW OF EXISTING ARMY STANDARD DESIGNS

The large standard magazines now in use are the steel circular arch 33-15-65, concrete circular arch 33-15-74, and semicircular steel arch 421-80-01. The present safety criteria document (DOD 6055.9-STD) dictates the use of these magazines for new construction. In 1987 a small box-type concrete magazine 422-15-01 was developed by the Corps of Engineers for storing 425 pounds of explosives. This magazine was developed to allow segregation of incompatible explosives and for separating material belonging to other organizations. This magazine also received DDESB's approval. Features of each magazine are presented below.

Steel Arch 33-15-65. This magazine, developed in 1963, is an earth-covered steel arch and is available in widths of approximately 8'-0", 10'-0", 12'-0" and 14'-0" feet. The length is variable from 11'-0" minimum with 2'-0" increments. The headwall as well as the rear wall of this magazine is of reinforced concrete construction. A double-leaf steel door 6'-0" wide by 6'-4" high and located in the headwall provides access to the magazine. This magazine does not have the stiffened headwall and door as shown on the later developed magazines. This therefore raises some doubt as to the adequacy of this type of magazine to prevent explosion communication since the headwall was proven by ESKIMO series test to be the weakest element of the magazine. It is important to point out a typographical error in the current version of DOD 6055.9-STD regarding this design. First, Chapter 5, Paragraph B.1.d. incorrectly refers to this standard as a 33-15-64. Secondly, all of Paragraph B is intended to identify standard designs capable of storing 500,000 lbs. The small size of this igloo would preclude it from containing such an amount.

Concrete Oval Arch, 33-15-74. The design of this magazine was originally developed by the U.S. Army Engineering Command in Europe and earlier referred to as the FRELOC magazine. In 1973 the magazine headwall and door were strengthened as a result of full scale ESKIMO tests. This magazine is 25 feet wide and 14 feet in height. The length varies but is normally constructed in 60 feet or 80 feet lengths. The standard design provides two door size options: an 8'-0 X 8'-0 and a 10'-0 X 10'-0 sliding stiffened door. The headwall of this magazine is 12 inches in thickness with thickened wall jambs and header beam.

Semicircular Steel Arch, 421-80-01. This magazine is an assemblage of components from various sources. Those components that are structurally critical from an explosives safety standpoint are traceable to DDESB blast tests and/or approved magazines. The magazine is a steel arch, 1 gage in thickness. In general, the magazine is very similar to the 33-15-74 magazine with the exception of the arch material. The headwall and the rear wall are of similar construction, including the exhaust

stack and the louver openings in the front wall. The standard magazine drawings provide an option for a 10'-0" X 10'-0" and an 8'-0" X 8'-0" door.

Concrete Cubicle Magazine, 422-15-01. This magazine developed in 1987 is an earth-covered concrete cubicle 10'-0" X 10'-0" X 10'-0" in dimensions. It has a single leaf door approximately 4'-0" wide by 7'-0" high. As indicated above, the magazine storage capacity is 425 pounds of class 1.1 high explosives.

Availability of Standard Magazines Drawings. The Huntsville Division, U. S. Army Corps of Engineers, maintains and updates the standard drawings for all approved Army magazines. The EP 1110-345-2, "Index of Design Drawings for Military Construction," lists Army standard magazines. Copies of the standard drawings can be obtained from the Huntsville Division upon request. See Reference 11 for the ordering address.

#### NONCONFORMING HYBRID DESIGNS

##### Using Nonapproved Headwalls or Doors on Standard Arch Magazines.

Safety investigations have revealed construction of standard magazines that have been modified to suit cost and operational requirements. A non-approved headwall/door on a standard magazine would render the magazine nonstandard. If the hybrid magazine is sited at minimum distance for standard magazine, an analysis must be performed to determine the storage quantity which would prevent propagation to another magazine or vice-versa.

##### Mixing Headwalls and Doors From One Standard With Another.

Another problem encountered is the mixing of headwalls/doors between standard magazines. If sited at minimum distances per DOD 6055.9-STD, an analysis must be performed to determine if the headwall/door is adequate in strength to prevent propagation.

##### Improper Siting of Standard

Any magazine, sited less than minimum distances shown in DOD 6055.9-STD, will have to be evaluated to determine the maximum amount of explosives that could be stored in these magazines.

## EVALUATION PROCEDURES FOR NON-CONFORMING DESIGNS/SITINGS

a. Analysis of Nonconforming Elements. The headwall, door, and cover must be evaluated against the requirements to prevent propagation. Any deviation from the standards elements must be analyzed to determine the capacity of these elements. If the headwall/door cannot provide Category III protection for the stored material from the loading shown in Figure 1, then these elements must be analyzed to determine what loading they can withstand and this load converted into an amount of explosives that can be stored in an adjacent igloo. In addition to the analysis, the evaluation should be compared to the ESKIMO test data.

b. Example of Deviation. In recent months, we have evaluated magazines developed from components of standard designs. The majority of these magazines did not reflect the strengthened headwall/doors as was proven by ESKIMO tests to conform to safety criteria. These magazines were classified nonstandard requiring siting per DOD 6055.9-STD criteria. There appears to be a lack of understanding at the installation level in developing new magazines for standard siting. Nonconforming magazines submitted for consideration as a standard magazine must include a detailed analysis to show the headwall/door to be sufficiently adequate in strength to prevent simultaneous detonations. This adequacy is determined at the time of design and final safety approval by comparing the design to the design criteria of the day.

c. Vintage Igloos Versus Standard Igloos. It is not appropriate to compare the structural capacity of vintage hybrid designs with that of current designs. Hybrid designs which received safety approval based on the regulations in use at the time represent a risk which was determined to be acceptable at that time. The user must understand the difference between a safety approval and the structural design limitations. A safety approval of this type allows for storage limits equal to the standard of the day. However, it may not in fact provide the protection of assets that is expected because of the reduced structural resistance. Safety approval is often interpreted to insure a level of asset protection, however, such protection is dependent on minimum structural performance which is not necessarily defined by the standard.

d. Magazines Controlled by the Grandfather Clause. Existing magazines, conforming to the safety manual current at the time of design or approved for a designated explosive limit, shall retain their classification, i.e. (standard or nonstandard). Any accepted deviation from these standards must be documented in the permanent records of the installation. The documentation must show the applicable safety criteria requirements in effect at the time the design was accepted by the approving agency (DDESB). The installation's file copy of DDESB's site submission should serve as sufficient documentation that the installation has complied with the safety criteria.

## CONCLUSIONS

The following conclusions represents our interpretation of the proper applications of DOD 6055.9-STD:

- a. The Standard is intended to provide criteria such that simultaneous propagations of explosions from magazine to magazine are prevented.
- b. The Standard identifies several magazines approved for the storage of up to 500,000 pounds NEW. The 33-15-64 is one of those magazines.
- c. However, Eskimo tests have clearly indicated that the doors and headwall of 33-15-64 were inadequate to provide the desired degree of assets protection.
- d. New construction using 33-15-64 is therefore not consistent with requirements imposed by items a and c listed above. Any interpretation of item b that assumes use of this magazine for new construction is therefore faulty.
- e. We interpret item b above as a safety decision by DDESB that an existing magazine may contain a certain NEW and the associated risk is acceptable. We do not interpret item b above as either permitting or encouraging new construction using designs known to be inadequate.
- f. Hybrid magazines can be sited at standard magazine distances if all components and specifically the headwall/door are equivalent in strength to standard magazines specified in DOD 6055.9-STD manual. Approval by DDESB prior to construction should be mandatory.
- g. Hybrid magazines not equivalent in strength to the standard approved magazines must be evaluated on a case-by-case basis and approved by DDESB prior to construction. Existing hybrid magazines should be reviewed to determine their strength and should be sited according to their strength.
- h. Modifications to any of the standard magazines listed in DOD 6055.9-STD manual will render these magazines nonstandard unless verified to be sufficient in strength to prevent simultaneous propagation.
- i. Users should not be mislead by the presence of older standard drawings in DDESB 6055.9-STD. All new construction should be based on current technical knowledge. At this time only two Army magazines are designed based on the latest technical data and test results for 500,000 lbs. These magazines' drawings were listed earlier in this paper in paragraph titled "Review of Existing Army Standard Designs".

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